

THE HURRICANE SEASON OF 1959

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1. GENERAL SUMMARY

Eleven tropical cyclones were noted in Atlantic waters during the hurricane season of 1959 (fig. 1). This number compares with an annual average of ten during the past 20–25 years. Since there is considerable doubt whether one storm—Edith—fully met all the criteria of a tropical cyclone, the 1959 season may be regarded as about normal. Except for hurricanes Gracie and Hannah in late September and early October, average intensity was unusually weak. However, seven of the eleven storms did reach hurricane intensity at one time or another during their history.

The season started early with the first tropical storm developing on May 28. Activity continued high during June and July. There was an unusual lack of activity in the tropical Atlantic during August and early September until Flora began to develop on September 9. Most of the tropical cyclone development was confined to the Gulf of Mexico and the western Atlantic and only one storm originally attained hurricane intensity east of longitude 50° W.

Three hurricanes—two barely of hurricane intensity—and four tropical cyclones of only storm intensity reached the coastline of the United States. Damage in the United States from these storms totaled about \$23½ million with 24 fatalities, 22 resulting from Gracie, the only major hurricane to reach the United States mainland. Except for the 33 deaths and extensive damage in Nova Scotia in connection with the hurricane of June 17–21, there were no other known deaths or even significant damage in North and Central America outside the United States from tropical cyclones. Damage and fatality statistics are shown in table 1. The damage statistics are estimates and are necessarily approximate.

The May circulation pattern [1] included a mean ridge over the eastern United States, averaging as much as 150 feet above normal at 700 mb. During the period May 28–June 1, the maximum positive height anomaly over the northeastern United States was 320 feet, with height deficits southeast of Bermuda and in the western Gulf of Mexico. This resulted in above normal easterly winds which is considered favorable for above normal tropical cyclone activity. One storm developed in the central and western Gulf of Mexico on May 28. A tropical development this early in the season in the Atlantic area is

somewhat rare; there have been seven tropical cyclones in May since 1932.

Tropical cyclone activity continued at an above normal rate during June and July with two storms in each month; one of only storm intensity, two barely of hurricane strength, and one (Debra) of somewhat more than minimal hurricane intensity. The 700-mb. circulation in June [2] was characterized by above normal heights from the extreme southeastern Pacific across California to the western Great Lakes region, with below normal heights off the United States Atlantic coast across southern Florida into the southern Gulf and northwestern Caribbean. As a result there was deeper than normal easterly flow in the Gulf of Mexico and northwestern Caribbean. However, the resemblance between the June 1959 circulation and that described by Ballenzweig [3] as favorable for Gulf of Mexico tropical cyclone development is at best only fair.

In July a positive mean 700-mb. height anomaly was centered over the northeastern United States and the Canadian Maritime Provinces. With negative anomalies extending from the Gulf of Mexico eastward over the subtropical Atlantic [4], this resulted in an above normal easterly flow north of the axis of the negative anomaly. But again resemblance to the departure from normal described by Ballenzweig as favorable to tropical storm formation is only fair.

Tropical cyclone activity in August was negligible. At 700 mb., positive height anomalies extended from the Great Lakes region across the northern Atlantic to the Baltic Sea with a strong negative anomaly centered about 30° N., 50° W. and with a weaker departure over Cuba [5]. Thus easterlies (westerlies) should have been stronger

TABLE 1.—Fatality and damage statistics, North Atlantic hurricane season 1959

Storm	Principal area affected	Deaths in United States	Deaths outside United States	Damage
Arlene.....	Louisiana.....	1	0	\$500,000
Unnamed.....	Nova Scotia.....	0	33	Considerable
	Southern Florida.....	0	0	1,656,000
Cindy.....	S. Carolina.....	1	0	75,000
Debra.....	Texas.....	0	0	7,000,000
Gracie.....	S. Carolina, Georgia, Virginia.....	22	0	14,000,000
Irene.....	Extreme northwestern Florida.....	0	0	Minor
Judith.....	Southern Florida.....	0	0	Minor
Total.....		24	33	\$23,231,000

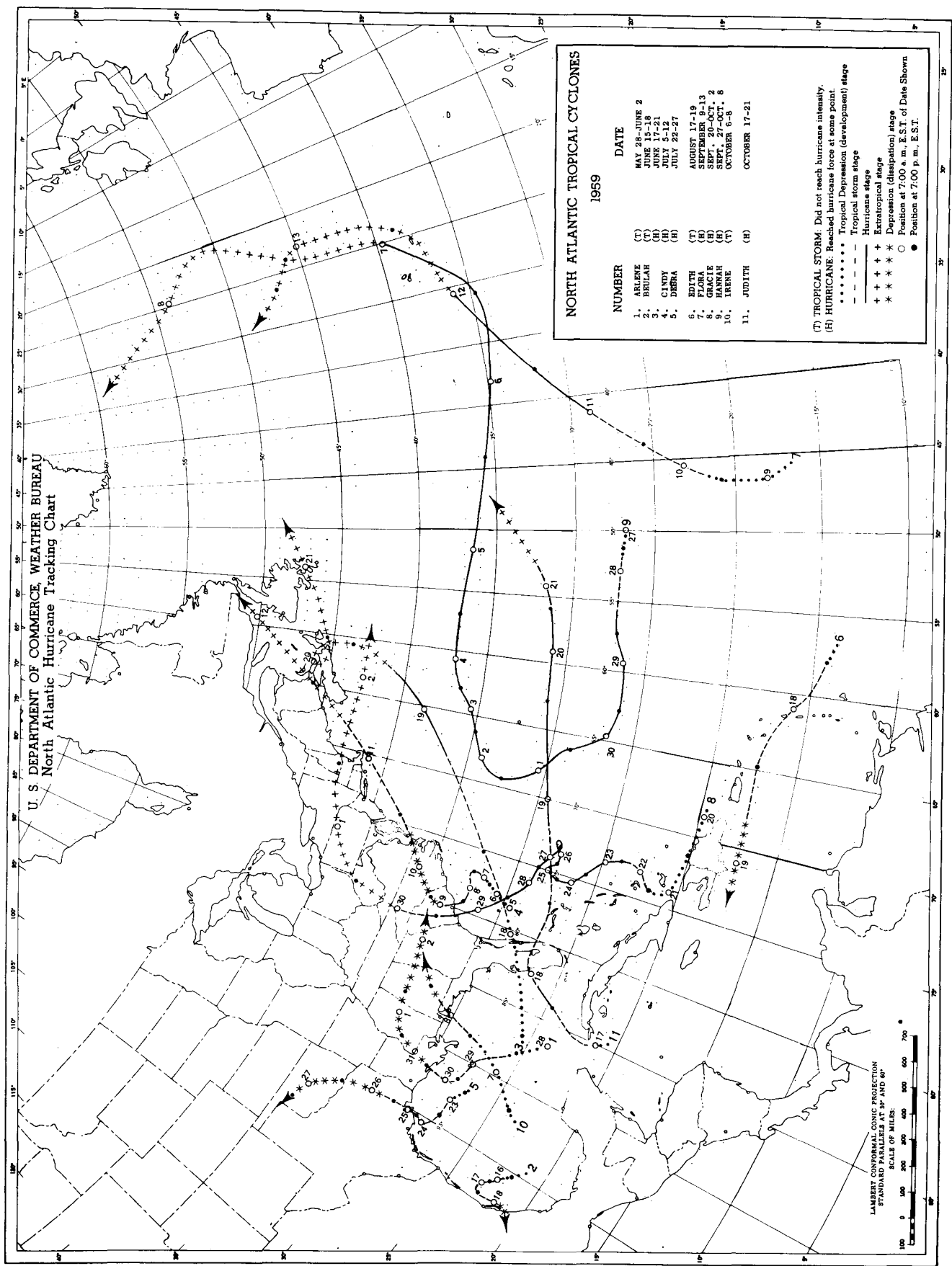


Figure 1.—Tracks of North Atlantic tropical cyclones of 1959.

(weaker) than normal between latitudes 25° – 30° N. and 45° – 50° N. However, the displacement of these anomalies was so far to the north that weakened westerlies were the principal result, but the easterlies were also weaker than usual. The August circulation appeared to approximate more closely the Ballenzweig [3] "favorable" than the "unfavorable" type. In the middle and upper troposphere a trough persisted in the middle Atlantic during much of the month and temperatures at these levels over the area of normal tropical cyclone development were apparently colder than normal.

In September, 700-mb. heights continued below normal over the subtropical portion of the western Atlantic and above normal over the northeastern United States and Canadian Maritime Provinces, resulting in a return to above normal easterly flow over the southern portion of the North Atlantic Ocean. Hurricane activity in September was normal or slightly higher. The trough in the middle Atlantic continued at high latitudes but did not extend as far south as in August.

2. INDIVIDUAL TROPICAL CYCLONES

Arlene, May 28–June 2.—Tropical storm Arlene originated in an easterly wave which was fairly well defined with a northeast-southwest orientation over the Dominican Republic as early as May 23. Shower activity indicating low stability was evident over a wide area including most of the Caribbean Sea and the Bahamas. At 0700 EST on the 25th, a weak cyclonic flow appeared at 500 mb. over the northwestern Caribbean, but there was no evidence of any concentrated bad weather. About this time a slow but definite increase in pressure gradient began north of western Cuba, leaving an extensive area of relatively slight gradient over the western Caribbean Sea. This trend in the pressure pattern continued until wind warnings were required for small craft on both coasts of Florida on May 27. The 500-mb. Low, had moved into the southeastern Gulf of Mexico on May 27 and on the 0700 EST surface chart of May 28 a ship reported a light southwest wind at 22.5° N., 86.5° W., providing the first indication that the closed circulation had extended down to the surface.

Ship reports during the evening of May 28 confirmed the development of tropical storm Arlene and the New Orleans Weather Bureau office at 2100 CST issued the first tropical storm advisory of the 1959 season. The storm center moved northwestward for about 12 hours from its initial position near 26° N., 88° W. Thereafter it moved westward for 12 hours, became stationary at 28° N., 92° W. during the night of May 29–30, and then moved northward across the Louisiana coast between Weeks Island and Pt. Au Fer, La., during the late afternoon of May 30. Winds diminished gradually after the center crossed the coast. The low pressure center later moved northeastward and eastward across northern Alabama

and Georgia. This was the earliest storm of record to cross the Louisiana coast.

Highest winds reported in the storm were 48 kt. with gusts to 65 kt. on the Louisiana coast. Lowest central pressure reported was 999.7 mb. at Patterson, La. Several ships and Navy reconnaissance aircraft also reported a central pressure of around 1,000 mb. while the storm was over the Gulf of Mexico. Highest tides were 3 feet above normal at Weeks Island and Pt. Au Fer, La. One man was drowned in the surf at Galveston.

The storm produced locally heavy rains over the southeastern portions of Louisiana and Mississippi. Moisant International Airport (New Orleans) received 11.09 inches in 24 hours and Houma, La., 11.35 inches from 0700 CST May 30 to 1030 CST May 31 and 13.13 inches in three days. Heavy rains associated with Arlene fell from southeastern Louisiana to northern Georgia resulting in some crop damage and serious flooding along some small streams; however, other property damage was slight. Total damage was estimated at approximately \$500,000.

Beulah, June 15–18.—Tropical Storm Beulah was first detected during the night of June 15–16 when the SS *Hondo* reported a 50-kt. northeasterly wind with heavy rain and high seas near 23° N., 96° W. The storm was short lived as it drifted northwestward on the 16th, westward during the 17th, and turned southward moving inland over Mexico south of Tampico on the 18th.

Highest winds were estimated by reconnaissance aircraft at 61 kt. with lowest pressure 987 mb. This is consistent with Fletcher's formula [6] for maximum wind based on minimum pressure. The storm weakened rapidly on turning southward late on the 17th, and winds were generally less than 30 kt. as it moved inland. No reports of damage have been received from Mexico; it was probably minor.

The synoptic situation contributing to the formation and dissipation of Beulah was rather complex. Pressure first began to fall over the western Gulf on June 13 with the movement of a weak cold front into the northern Gulf. A rather strong anticyclone centered over the Great Lakes contributed to a marked increase in the easterly flow over the northern Gulf. This High broke down rapidly on the 15th and 16th with the approach of an active short wave from the Plains States, probably one of the factors that prevented Beulah from becoming a well developed storm. At the 500-mb level, a very deep Low was located over the New England States throughout this period with short waves "digging" southeastward into the Mid-Atlantic States. In the upper troposphere, conditions became favorable for development in the western Gulf after a weak trough at 200 mb. in that area began to retrograde causing winds at Corpus Christi and Brownsville to shift from northwest on the 14th to south and southwest on the 15th. This condition was short lived as upper winds again shifted to west and northwest with the approach of an active short wave at middle latitudes on the 17th.

Unnamed Hurricane, June 17-21.—While Beulah was developing in the southwestern Gulf of Mexico, an unstable easterly wave was noted in the northwestern Caribbean on June 15. This wave moved northwestward into the central Gulf on the 16th and a weak closed circulation appeared in the east-central Gulf on the 17th. It began moving northeastward, while at the same time Beulah in the extreme western Gulf was drifting west and south.

When the tropical depression was still about 350 miles west of Miami, a tornado moved across the city of Miami at about 10 p.m. EST on the 17th, lasting 20-30 minutes and causing approximately \$1,500,000 damage, many injuries, but no deaths. At the same time another tornado formed north of West Palm Beach and lasted about 20 minutes but fortunately traversed a sparsely inhabited area. The tropical cyclone moved across central Florida during the night of June 17-18 attended by heavy rains and gusty winds, fluctuating rapidly in the Sarasota-Bradenton area from 9-13 kt. to 43 kt. Tides $2\frac{1}{2}$ to 3 feet above normal were reported along the beaches from St. Petersburg to Naples causing damage estimated at \$156,000. The torrential rains following previous heavy rainfall caused considerable additional damage to crops, particularly in the Fort Myers area.

Several bulletins on this storm were issued by the Miami Hurricane Center. The last, on the afternoon of June 18, indicated winds of 43 to 56 kt., and the likelihood of additional development, and contained cautionary advices to shipping.

After passing off the Florida east coast the storm deepened steadily and at 0250 GMT on the 19th, the *Atlantic Union* reported a barometer reading of 993 mb., falling, and west-southwesterly winds occasionally 80 kt. Although the hurricane was in a diffused frontal zone, it now appears to have remained warm-core and essentially tropical for some time. The lowest reported pressure was 974 mb. The hurricane struck the Canadian Maritime Provinces in the vicinity of Northumberland Straits. Associated wind and barometric data as the storm moved inland are lacking, but the press reported 33 deaths, mostly lobster fishermen, and considerable property damage. Notices of this severe storm had been carried in the NSS bulletins.

Cindy, July 5-12.—The fourth tropical cyclone of the season, Cindy, barely reached hurricane force before it crossed the coastline north of Charleston, S.C., on July 8. The circulation which produced the storm had been noticed first some three days earlier off the Florida upper east coast. A deepening low pressure system had moved from the Great Lakes to the Canadian Maritime Provinces while the associated cold front moved southeastward and became stationary from near Bermuda to extreme northern Florida. With the fracture of the short-wave trough, a cut-off Low developed off the south Atlantic coast—most pronounced at the 500-mb. level. Usually tropical storms forming in this type of

situation develop slowly, remain small, and seldom intensify to much more than minimal hurricane strength. Cindy conformed to this pattern.

On July 6, winds just east of the center increased to 26-35 kt. as convective activity, evidenced by numerous showers extending outward some 200 miles to the north, contributed to the conversion from a cold to a warm-core system. An intensifying anticyclone increased the easterly gradient north of the center and Cindy developed and intensified. A reconnaissance plane located the eye late on the afternoon of the 7th some 190 miles east of Charleston with maximum winds 52 to 56 kt. and minimum pressure 997 mb. The small storm moved northwestward, reaching hurricane intensity a short distance offshore, and the center made landfall about 0245 GMT on the 9th between Charleston and Georgetown, S.C. Winds of 56 kt. were recorded at McClellanville, a short distance inland, with squalls estimated at just about hurricane force in the sparsely settled coastal area. The storm tide was about 4 feet above normal near the center.

The storm curved northward through South Carolina on the 9th and then turned northeastward at a little faster rate to the southern tip of Chesapeake Bay by late afternoon on July 10. The sustained winds had dropped rapidly after the center moved inland but gusts up to 39 kt. were still occurring at this time. As the remains of the circulation moved back into the Atlantic, marked re-intensification took place. At 0600 GMT, with the center some 75-100 miles off the New Jersey coast, the ship *Ocean Monarch* reported winds of 65 kt. just southeast of the center, and other ships reported 45 to 50 kt. Accelerating northeastward, Cindy had passed across Cape Cod by 1200 GMT July 11. Winds were generally 22 to 35 kt. along the coast but ranged up to 35 to 52 kt. over the open waters just east of the center with a gust of 59 kt. at Block Island, R.I.

The intimate association of tropical storm behavior with features in the westerlies is well illustrated by Cindy. Three successive short waves played important roles. The passage of the first of these across the northeastern United States was followed by the development of the cut-off Low in which Cindy formed. The increase to storm intensity occurred as the next trough passed and the storm was then deflected abruptly to the west by the following anticyclone. Finally, the intensification on moving back to sea can probably be related in part to the passage of the third short wave in the series across the northeastern United States at that time. Some re-intensification often occurs when a tropical storm moves from land to sea but the marked deepening of Cindy was more than would normally be expected after allowing for decreased surface friction and increased moisture supply but relatively low water surface temperatures. However, it is significant that, coincidental with the movement of Cindy off the coast, a short wave passed to the north with a strong jet maximum (120 kt.

or higher at 200 mb.) moving through New England. The divergence pattern associated with this jet was such as to favor high-level outflow from the storm, contributing to re-intensification.

While Cindy was not typical of storms which develop in deep easterlies south of the subtropical ridge, its behavior does emphasize the necessity of recognizing and anticipating the effects of patterns in the westerlies on tropical cyclones.

Since Cindy was small, of minimal hurricane intensity, and did not strike a thickly populated area, property damage was relatively minor. The only casualty reported was a man killed near McClellanville, S.C., when his automobile collided with a fallen tree. Wind damaged some roofs and blew down trees and power lines in South Carolina and some damage to buildings resulted from several small tornadoes attending the storm in northeastern North Carolina and southeastern Virginia. Heavy rains occurred along and near the storm path through South Carolina, North Carolina, southeastern Virginia, and the immediate coastal areas northward to Maine. The largest precipitation amounts were in South Carolina with 6 to 8 inches general through central portions of the State and unofficial but reliable reports of up to 15 inches near Columbia. Local flooding of lowlands resulted but no major flood situations developed and the rains in the Carolinas were largely beneficial as they relieved a drought situation.

Debra, July 22-27.—The beginning of hurricane Debra can probably be traced back to July 15. Considerable shower and thundershower activity began about this time in the western Bahamas and over Florida, under the influence of a cold-core vortex which developed in the high troposphere and at 500 mb. drifted slowly southwestward through the western Bahamas, over western Cuba, and into the east Gulf of Mexico by the 20th. The activity spread into the Gulf as the upper circulation flattened into an inverted trough and continued westward.

The first weak surface circulation, detected as early as 1900 EST on the 20th, later developed into hurricane Debra over the northwestern Gulf of Mexico. The circulation continued weak until the 23d, when winds up to 22-30 kt. accompanied showers and squalls in the northwestern Gulf and along the Louisiana and upper Texas coasts.

An indication that some intense weather was in the making in the western Gulf of Mexico came from the SS *Atlantic Navigator* (at 0000 GMT on the 24th at 23.7° N., 94.5° W.) which reported a northwest wind of 32 kt. with rough seas from the southwest. This was later corrected to southwest wind of 23 kt. The report indicated that a vortex was developing, which was later verified by reports from that area and to the north toward the Texas coast during the next 12 to 18 hours.

A delayed observation, received at 1130 GMT on the 24th from the ship *Mexican Trader* (located at 28.0° N., 94.2° W.) reporting a surface wind from the southwest at 40 kt. and

pressure of 1007.5 mb., indicated additional intensification. At 1200 GMT this ship had moved about 60 miles west and the surface winds had increased to southwest 50 kt. That Debra was already a fully developed hurricane is evidenced by the radar photograph (fig. 2) taken at the Dow Chemical Plant in Freeport at 0733 CST July 24 when the set was turned on. No spiral organization had been noted on the radar scope the previous afternoon.

Reconnaissance aircraft located the center of tropical storm Debra during the early forenoon of July 24. It seems likely the plane did not pass through the most severe squalls prevailing at the time.

Hurricane Debra increased further in intensity during the afternoon and evening of July 24 and passed inland on the Texas coast between Freeport and Galveston near midnight on the 24th. It continued slowly northward across extreme eastern Texas and rapidly lost intensity on the 25th and 26th, and finally lost its identity in central Oklahoma on the 27th.

The subtropical ridge, surface and aloft, was fairly well established over the Atlantic and westward across the Gulf States, while the easterly wave in which Debra was spawned moved from the Bahamas across the Florida Straits and the Gulf of Mexico. At about the time that Debra intensified and became a hurricane, a polar trough moved eastward into the central portion of the United States. This was responsible for the southerly shift of winds at 500 mb. and above that steered Debra northward instead of west-northwestward or northwestward which seemed indicated earlier.

The lowest reported central pressure in hurricane Debra was 984.4 mb. from the Coast Guard Cutter *Cahoone* late on July 24. Dickinson, Tex. reported 986.5 mb., the lowest reading from a land station. Highest reported wind was 70 to 78 kt. with gusts to 91 kt. from Brazos Floodgates near Freeport, Tex. Tides were generally 3 to 5 feet above normal over Galveston Bay. Morgan Point, at the head, or north, end of Galveston Bay, reported the highest tide of 7.9 feet m.s.l. Rainfall was heavy throughout eastern Texas and extreme western Louisiana; Orange, Tex., reported the greatest amount, 14.42 inches.

No casualties occurred in connection with Debra, but ten persons suffered minor injuries in Brazoria County, Tex. Damage in Brazoria, Galveston, and the eastern portion of Harris County, Tex., was estimated at \$6,685,000 with some additional in other areas.

Development so close to the coastline is rather unusual and the forecast problem was complicated by lack of ship reports, and delays and transmission errors in the few that were received.

Edith, August 17-19.—Tropical storm Edith formed in an easterly wave in the Atlantic Ocean east of the Windward Islands. At 1530 EST, August 17, reconnaissance aircraft found a weak center near 13.8° N., 57.2° W. The minimum surface pressure was 1007 mb., while highest winds were 30 kt. in squalls north of the center. The

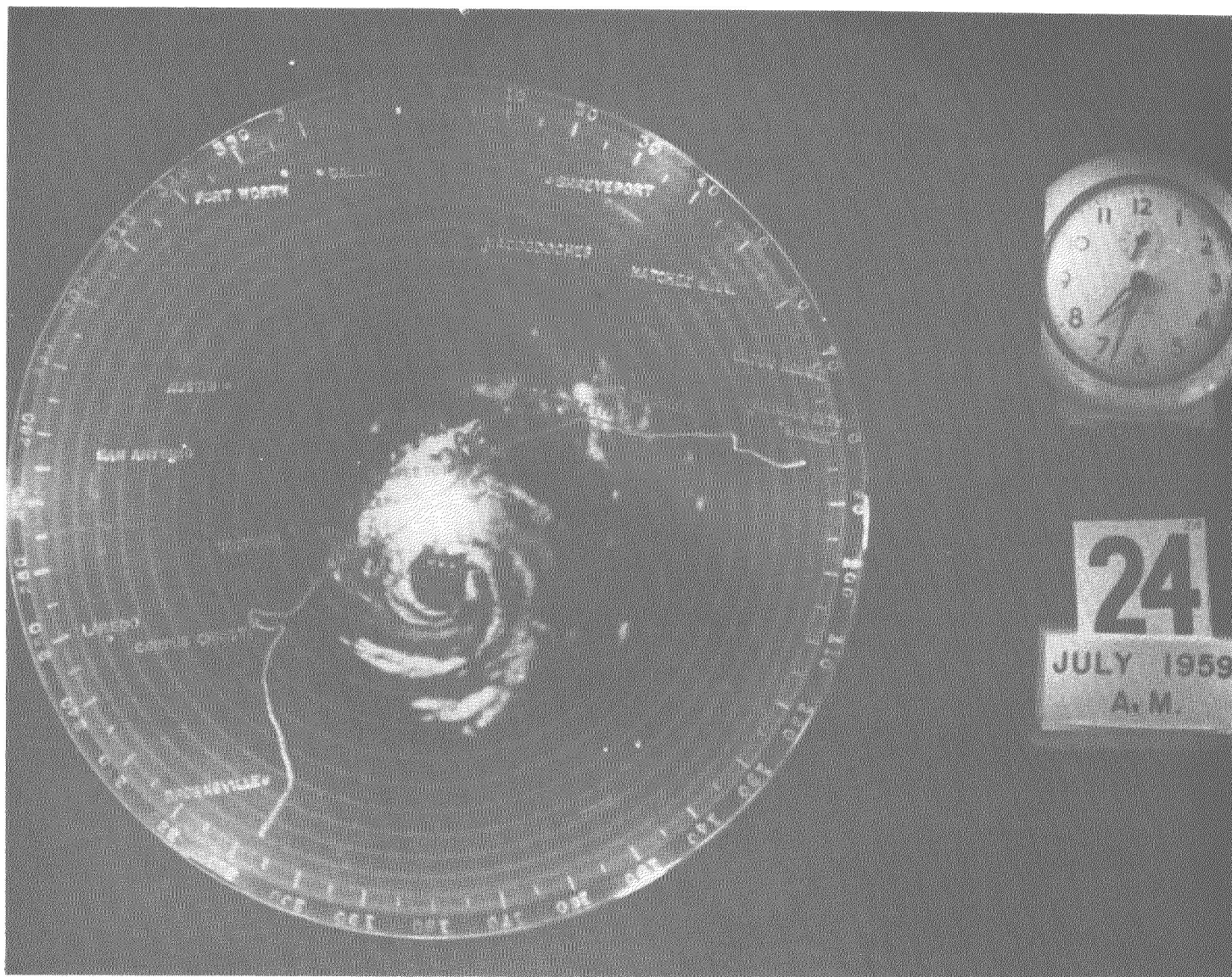


FIGURE 2.—Radar picture of hurricane Debra taken when the hurricane was just off the coast. (Courtesy Roy C. Jorgensen, Dow Chemical Company, Freeport, Tex.)

storm was never well defined as it moved on a west-northwestward course with an average speed of 20 kt., passing through the Leeward Islands in the vicinity of Guadeloupe early on the 18th. Highest winds never exceeded 48 kt. and the storm dissipated just to the south of Mona Passage during the night of August 18–19. Indeed, there is considerable doubt if a complete circulation ever existed and whether this disturbance meets the specifications for a tropical storm.

There were two important synoptic features associated with this storm. Very warm air was observed in the middle troposphere just prior to formation, and the wind field in the high troposphere never became favorable for high-level evacuation.

There were no reports of loss of life or of damage attributable to Edith.

Flora, September 9–13.—The history of the formation of Flora is rather uncertain beyond about 24 hours prior to the first advisory issued at noon EST, September 10. However, four days earlier, on the afternoon of September 6, pressure and wind in the Cape Verde Islands indicated a trough passage. This trough could not be followed from day to day through the ocean area due to a lack of reports, but if it moved at an average speed of 13 kt. it would have reached the position where Flora was found on September 10 near latitude 22.1° N., longitude 46.3° W. Ship and aircraft reports indicated highest winds of 39 kt. and minimum central pressure of 1008.1 mb. Succeeding positions of the storm center indicated that it was already on a northerly course and it continued to curve through northeastward to east-northeastward, crossing the southernmost islands of the Azores group late on September

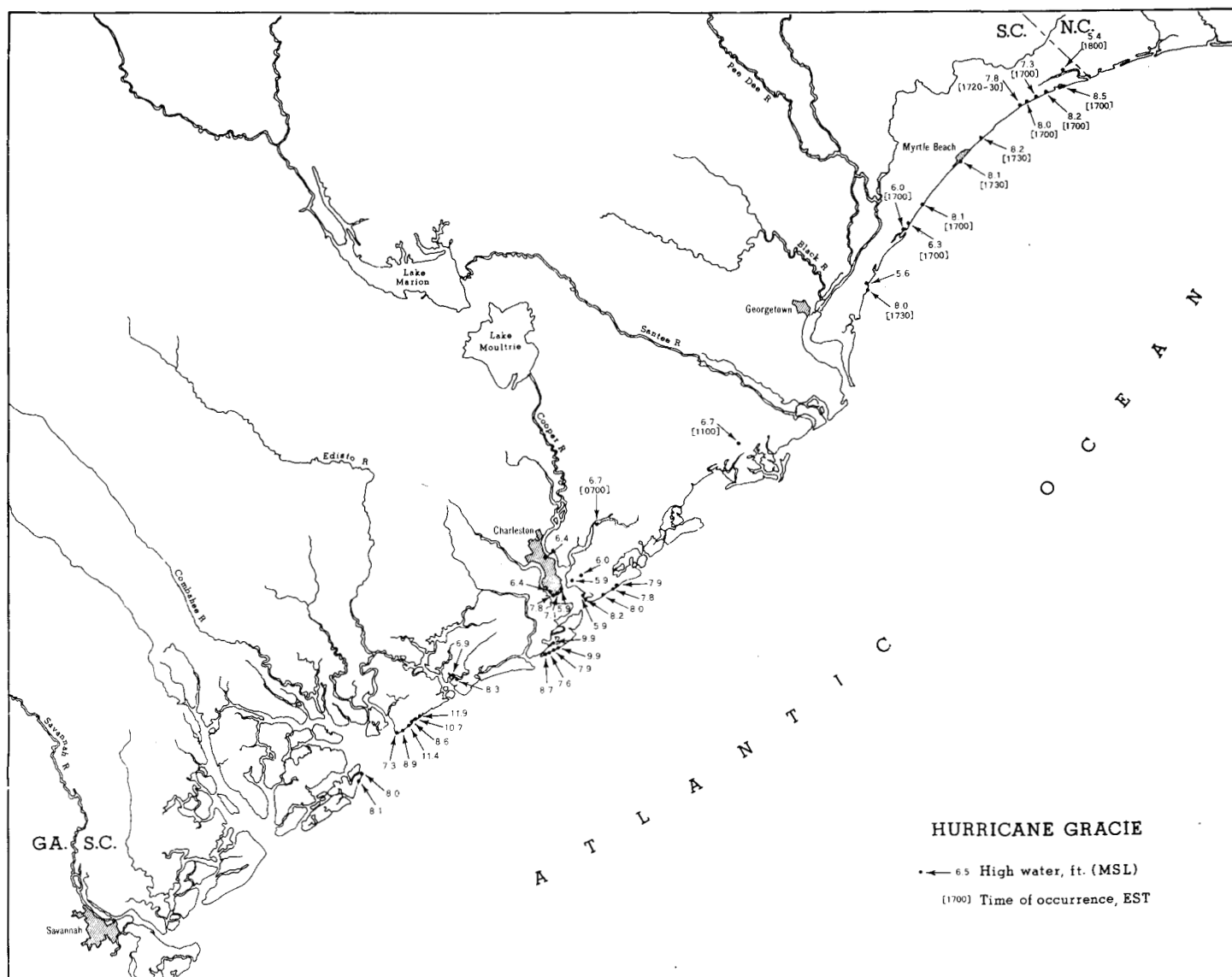


FIGURE 3.—High water (ft., m.s.l.) recorded during hurricane Gracie, September 1959.

12. Later the same day reconnaissance aircraft found no evidence of a tropical storm as it combined with a cold front and moved into a large polar Low.

By mid-morning of September 11, aircraft found that Flora's winds had increased to barely hurricane force, 65 kt., and the minimum pressure was 994 mb. The next highest wind speed reported was 60 kt. on the afternoon of the same day when central pressure had risen to 1001.0 mb. On September 12, although a lower pressure of 994.2 mb. was measured as the storm became extratropical, highest surface winds were about 45 kt.

Flora recurved quickly to the north and northeastward before she became a threat to any land areas except the Azores islands, due to a major trough in the westerlies extending southward into the Tropics. No loss of life or property damage has been attributed to Flora.

Gracie, September 20–October 2.—Gracie, a major hurricane, was one of the most troublesome storms of the 1959 season to forecast. The easterly wave in which it formed had been followed for some 5 days and its sudden development and intensification is difficult to explain. Gracie's erratic movement between the 22d and the 27th, when at one time or another it moved in about every direction of the compass (see fig. 1), proved impossible to forecast in detail. The winds in the southwestern Atlantic during this period at all levels were extremely light and variable and there was no well defined steering current. The storm began moving slowly but steadily toward the west-northwest on the 27th and continued toward the west-northwest and northwest, passing inland on the South Carolina coast near Beaufort around noon on the 29th.

The easterly wave in which Gracie developed was first

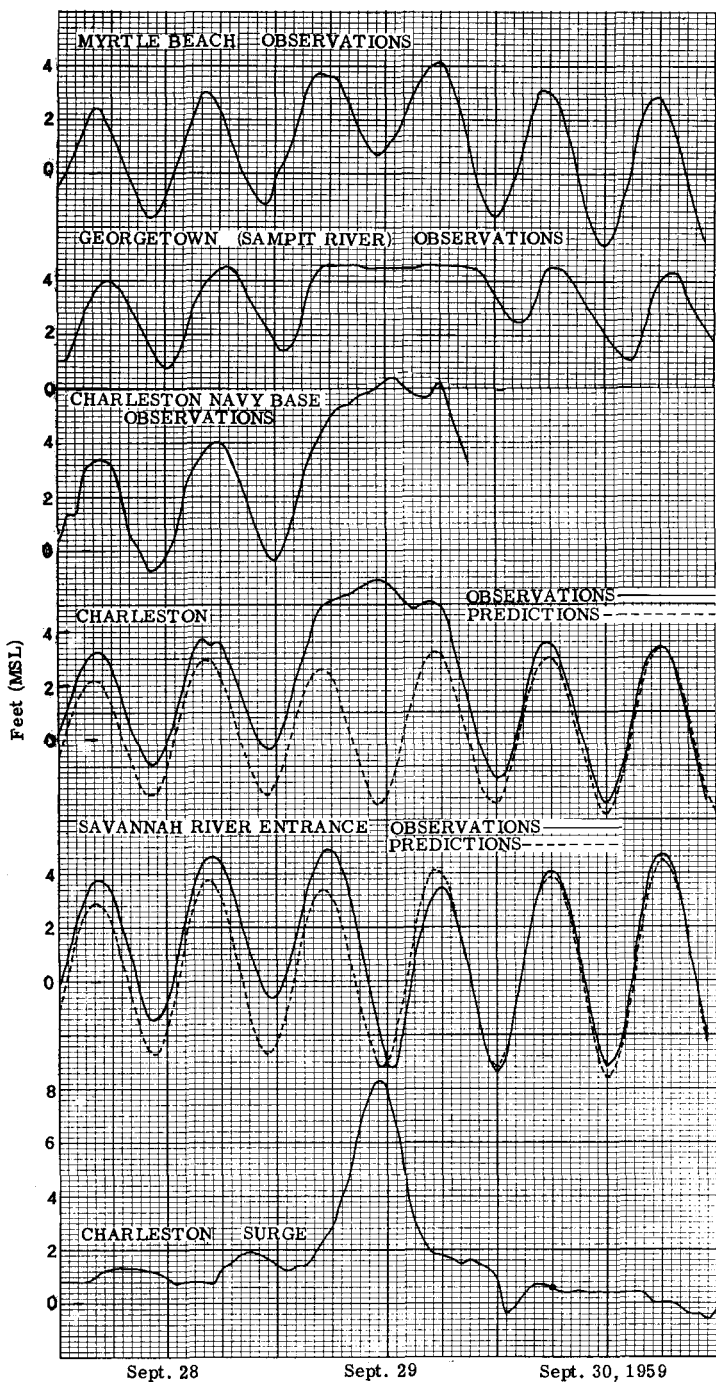


FIGURE 4.—Observed and predicted tides along the South Carolina coast preceding, during, and following hurricane Gracie, September 1959.

noted on September 16 about midway between the Lesser Antilles and Africa. It moved westward at about 17 kt. during the next 5 days eventually moving into the southeastern Bahamas. The wave was investigated daily by reconnaissance aircraft beginning on the 18th and no closed circulation was found until the 22d. Indeed, the wave remained remarkably constant in all details and was attended by heavy shower activity from the time first

noted. The island of Mayaguana in the southeastern Bahamas reported 8.40 inches of rain during the 12-hour period from 1900 EST on the 21st to 0700 EST on the 22d. The hurricane was quite wet throughout its history.

The surface pressure pattern over the Atlantic from September 16–29 was about normal. The most important feature was the movement of a strong polar anticyclone from the northern United States into the western Atlantic, resulting in strong anticyclogenesis and an increase in low-level easterlies in the southwestern Atlantic. The initially cold High was gradually transformed into a warm anticyclone which extended well into the middle troposphere. However, weak short waves in the polar westerlies to the north of the hurricane shortly weakened the high and resulted in a very weak steering current. Not until the 27th, when rising heights in the middle troposphere north and northwest of Bermuda increased the easterly current, did hurricane Gracie develop a relatively straightforward movement.

At 200 mb. a moderately strong high pressure cell existed about over and to the east and northeast of Gracie during September 22–24, but as Gracie drifted northward the High eventually became located south and southeast of the hurricane by the 25th and 26th. During this whole period the circulation in the upper troposphere was very complex and contained many small-scale cyclonic and anticyclonic eddies. On the 28th and 29th the overall anticyclonic flow had simplified greatly and the center of the upper level High again became located north and northeast of Gracie resulting in a rather uniform steering current from the east-southeast throughout the entire troposphere.

The intensity of hurricane Gracie was as erratic as its movement. On September 22 the storm deepened rather rapidly to 997 mb. with winds 78 to 87 kt. On the 23d and 24th, central pressure varied from 1000 to 1006 mb. with winds from 45 to 65 kt. On the 25th the minimum barometer again dropped to 997 mb. and reconnaissance aircraft reported an increase in maximum winds, the size of the storm area, and the intensity of weather around the eye. On the 27th the central pressure decreased further to 979 mb. with an almost complete wall cloud. The hurricane continued to intensify further during the next 2 days to 950 mb.

The center of the hurricane crossed the coast near Beaufort, S.C., near noon on September 29. The Marine Corps Auxiliary Air Station at Beaufort reported a minimum barometer reading of 950 mb., a sustained 5-minute wind of 84 kt., and gusts estimated to 120 kt. Wind was estimated as high as 152 kt. closer to the exact center of the storm and gusts as high as 130 kt. seem quite credible. After moving inland the hurricane weakened gradually as it turned northward along the Appalachians.

Rainfall of 3 to 8 inches occurred in South Carolina and portions of Georgia, while in North Carolina 2 to 4 inches were reported with local amounts up to 8 to 10 inches.

Some flooding occurred, particularly in the Carolinas and Virginia and crop damage, due to wind and rain, was heavy in South Carolina and eastern Georgia. The rainfall was generally beneficial in most sections from North Carolina northward ameliorating near drought conditions in many areas.

A series of tornadoes attended the passage of the dying storm through Virginia and 12 persons were killed in one tornado at Ivy near Charlottesville. Ten others lost their lives in South Carolina and Georgia, mainly due to automobile accidents, falling trees, and live wires. Wind damage was severe near the eye in the coastal area as Gracie moved inland and was described as the most severe in the history of Beaufort, S.C. Damage has been estimated at \$14,000,000, about half occurring in Charleston County, S.C.

Accurate detailed prediction of the extremely erratic course of this hurricane during its early stages was beyond the capability of the science at this time. After the steering current simplified early on the 27th, forecasts and warnings issued in connection with Gracie were exceptionally accurate. A hurricane watch was announced for the area from Savannah, Ga. to Wilmington, N.C., at 1100 EST, September 28, and hurricane warnings were issued at 1400 EST on the 28th for the area from Savannah to Wilmington. As a result of the accurate warnings, evacuation from vulnerable islands and beaches was almost total. Effective community action on the basis of these warnings and the landfall of Gracie near the time of normal low tide were responsible for the low loss of life. Indeed, there were no known fatalities from hurricane tides and waves. The maximum tide was about 9 to 12 feet m.s.l. [7], (see fig. 3).

Figure 4 shows the continuous tide record at Charleston, S.C. It can be seen that the peak difference coincided within an hour with low tide. The high water marks in figure 3 would undoubtedly have been much higher if the storm center had reached the coast either a few hours earlier or later than it actually did.

Hannah, September 27–October 8.—On September 27, when hurricane Gracie was some 300 miles off the Florida east coast, ship reports indicated the development of a *broad cyclonic circulation centered in the Atlantic near latitude 27° N., longitude 50° W.* Aircraft reconnaissance the next day found a fully developed hurricane circulation and the first advisory on Hannah was issued at 2300 GMT, September 28. The hurricane at this time was located near 27° N., 57° W. and was moving toward the west at about 14 kt. with highest winds around 74 kt.

Hannah increased in intensity during the next 48 hours with central pressure dropping to 959 mb. and maximum winds reaching 108 kt. Minimum pressure and intensity remained about the same during the next three days as the storm curved northward about 200 miles west of Bermuda and then accelerated to about 17 kt. toward the east on October 4. The last advisory was issued when the hurricane was 200 miles south-southwest of the Azores on

October 6. Winds near the center at this time were still estimated at 87 kt. Details of later stages are lacking but indications are that a gradual decrease in intensity then began as the storm moved northeastward, merging with an intense cyclone centered southeast of Greenland.

Upper air data in the area traversed by Hannah are too sparse to permit a comprehensive study of factors associated with its development. The 500- and 200-mb. charts indicate that the initial circulation formed under the eastern side of a progressive upper trough extending southward from the southern tip of Greenland. As the northern portion of the trough continued eastward and the developing hurricane moved westward, it passed to the south of a strong 500-mb. anticyclone, the same High which was associated with hurricane Gracie, and this was the period of maximum intensity of Hannah. Eastward motion of this High permitted first Gracie and later Hannah to recurve.

Hurricane Hannah never became a serious threat to the United States coast, or to Bermuda, and it presented no particularly difficult forecast problems. The most unusual feature of the storm was its long life and sustained intensity, somewhat similar to hurricane Carrie of 1957. A hurricane beacon developed cooperatively by the Air Force Geophysics Research Directorate and the Weather Bureau was tested in the hurricane on October 1–4. Some highly encouraging results were obtained since the beacon balloon remained in and transmitted signals from the eye for 24 hours on one occasion.

Irene, October 6–8.—Tropical storm Irene formed on October 6 in the central portion of the Gulf of Mexico and moved north-northeastward during the next two days. The lowest sea level pressure reported by reconnaissance aircraft was 1001 mb. The highest winds were gusts of 48 kt. in squalls at the Pensacola Airport. Irene was never a well organized storm and although the center moved inland near Pensacola early on the 8th, highest tides were 4.4 feet above normal at Cedar Keys, Fla., a considerable distance east of the track and landfall.

Prior to the development of Irene, a short wave with surface cyclogenesis moved through the southern Plains and Texas on October 4. This permitted the trailing cold front to move into the western Gulf of Mexico on the 5th; the front then dissipated leaving a rather sharp trough. At 500 mb., temperatures over the western Gulf were relatively warm. At 200 mb., a weak anticyclone persisted over the surface development.

No deaths were reported and damage was not significant.

Judith, October 17–21.—Activity along the intertropical convergence zone continued strong throughout mid-October in the Caribbean and Central America area. Pilots reported 52-kt. squalls in the vicinity of 15° N., 73° W., late on the 10th and early on the 11th, but the perturbation continued along the ITC with no development. During the afternoon of the 11th a new unstable easterly wave approached the Leeward Islands, and Barbados experienced heavy squalls. This wave moved steadily across

the Caribbean at 15 kt. and on October 15 developed a weak circulation south of Jamaica. During this same period, a tropical low pressure pattern gradually developed in the Bay of Campeche, remaining essentially stationary, while a cold front moved slowly southeastward from Texas into the western Gulf of Mexico.

On the morning of October 16, the Caribbean wave had drifted into the Gulf of Honduras, the Campeche depression had weakened, and the west Gulf front had become diffused. Squalliness had decreased although moderate squalls were still occurring as far east as Jamaica. The Caribbean wave had been investigated daily by aircraft reconnaissance and, since development was thought possible when the two disturbances eventually merged in the south-central Gulf, arrangements were made for aircraft reconnaissance in the area the following day.

At both 1300 EST and 1900 EST on the 16th, all reporting stations within 500 miles of the disturbed area reported 24-hour rises in surface pressure. However, surface reports at 0700 EST on the 17th, as well as aircraft reconnaissance during the forenoon, indicated a complete circulation. Gale warnings were issued for the Florida Gulf coast south of Cedar Keys at 1600 EST as gradual intensification occurred during the day.

In the afternoon, shortly before departing for home base, the aircraft reported a new center apparently developing some 150 miles northeast of the old center, with 45-kt. surface winds. At 1700 EST, the MV *Italsole* encountered a small vortex at 24.5° N., 83.7° W. with the barometer falling rapidly from 1008.5 to 999.3 mb., and the wind increasing to 43 kt. The wind shifted gradually from east-southeast to southwest in 30 minutes. The barometer then began rising steadily. An hour or two later another ship in the same area reported winds of hurricane force. With fairly rapid intensification indicated by these ships and by aircraft and with direction of movement in doubt, hurricane warnings were issued at 2030 EST for the Florida Gulf coast from Punta Gorda to Cedar Keys.

The observer at Dry Tortugas, some 70 miles west of Key West, reports as follows:

Late in the afternoon, Cuban fishing boats in the area came to Dry Tortugas harbor area to avoid rough water. Just before dark the wind began to pick up, and in about 5 minutes the wind increased from about 10 m.p.h. to about 50 m.p.h. and the ocean became extremely rough. The high winds (about 50-55 m.p.h.) continued, developing waves of nearly 10 feet. The wind shifted from east to south and blew all night at about 50-55 m.p.h., although the rain did not get above a heavy drizzle.

Neither the Miami WBO radar (the new WSR-57) nor the reconnaissance aircraft radar could pick up any wall cloud around the eye during the night and thus it was difficult to track the storm center. With time, the weather bands observed on radar appeared to lose intensity as well as much of their spiral character. These radar observa-

tions and weather trends along the Florida Gulf coast indicated definite loss of intensity and hurricane warnings were changed to gale warnings at 0500 EST.

The storm center reached the coast near Boca Grande Island between 0800 and 0900 EST on the 18th, with lowest pressure 999.0 mb., and very little wind north of the center. South of the center the maximum sustained velocity at Fort Myers was south-southwest 35 kt., and gusts to 46 kt. Total rainfall was 7.57 inches and highest tides 2½ feet above normal. There were no deaths but one injury.

The storm crossed the Florida peninsula during the 18th, passing into the Atlantic near Fort Pierce. Gales were reported over extreme southern Florida with gusts of 48 kt. at Miami. Within a few hours after the storm passed out to sea, a new center apparently developed just northeast of Great Abaco Island in the Bahamas and began to intensify, reaching hurricane force by the next morning. Again the strongest winds first appeared on the south side of the center but gradually extended completely around the storm.

During the period of tropical storm and hurricane intensity, Judith moved in good agreement with the 500-mb. steering. In the high troposphere (200 mb.) winds were westerly in a relatively cold trough as the wave moved across the eastern and central Caribbean and no intensification occurred. The trough narrowed and began to fracture during the night of the 14th and a high pressure pattern developed over the eastern Caribbean. As the wave passed under a band of southerly winds between the trough and the High some intensification took place, which ended as the surface Low passed under the high-troposphere Low. Redevelopment began as the surface disturbance passed under the high-level ridge in the extreme southeastern Gulf. No explanation is available for Judith's loss of intensity in the 6- to 8-hour period prior to landfall on the Florida west coast. Re-intensification over the Atlantic took place under west-southwesterly winds of around 45 kt. at 200 mb.

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